FACULTY:
SCHOOL OF CHEMICAL AND ENERGY ENGINEERING

SETK 3323
SEPARATION PROCESSES

SECTION: 01

CORNERSTONE PROJECT 25/26

LECTURER'S NAME:
DR SHUHADA ATIKA IDRUS SAIDI

NAME	MATRIC NO.
CHANG QING YIU	A23KT0049
CHEONG WEI XIN	A23KT0051
E SHAO YUAN	A23KT0064
YONG ZHENG ZHAO	A23KT0254

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1.0 INTRODUCTION

In this Cornerstone Project, students are tasked to design distillation columns which are involved in the amination of 100,000 MTA of Ethylene Oxide (EO) for Monoethanolamine (MEA) production. The calculations of mass balance and energy balance which had been done in the previous semester were revised, and two unit operations were selected, which are Distillation Column 1, DC1 and Distillation Column 3, DC3, to be designed. Excel Spreadsheet is used to perform calculations to aid the process of determining the prior parameters of the distillation column, which are the type of the column, the diameter of the column, the height of the column and the number of trays for trays column.

2.0 METHODOLOGY

2.1 TRAY TOWER

➢ **Distillation Column 1**

a. *Number of trays*

The calculation starts by determining the light key component and heavy key component. MEA is determined as the light key component, while DEA as the heavy key component according to their volatility. By using Antoine Equation, P_{sat} of each component is calculated by assuming a boiling point temperature. The temperature which yields a sum of the P_{sat} of each component equals the pressure of the feed stream is the boiling point temperature of the feed stream, which $T_{bp,feed}$ equals 46.819 °C. By comparing $T_{bp,feed}$ and T_{feed}, it is determined that the feed is a cold feed, hence q > 1, the value of q can be determined by:

$$q = \frac{(H_v - H_L) + C_{pL}(T_B - T_F)}{H_v - H_L}$$

The value of q obtained is q = 1.1435. By using Underwood's Shortcut Method, $1 - q = \Sigma \frac{\alpha_i X_{iF}}{\alpha_i - \theta}$ is used to calculate θ by trial and error , $\alpha_{LK} < \theta < \alpha_{HK}$. The θ is calculated using the Goal Seek function, the value obtained is 1.0427. The calculated R_m value is 0.0294 by using $R_m + 1 = \Sigma \frac{\alpha_i X_{iD}}{\alpha_i - \theta}$, since the value is too small, R_m is assumed to be 0.25, followed by assumption of reflux ratio R = 1.5 R_m . Fenske Equation is used to calculate the N_m:

$$N_m = \frac{log((\frac{x_{LD}D}{x_{HD}D})(\frac{x_{HW}W}{x_{LW}W}))}{log(\alpha_L, av)}$$

Erbar-Maddox Correlation is applied in order to determine the $N : N_m$ ratio, which equals to 0.40. N is determined to be 7.0739 theoretical stages, which is 6.0739 trays + 1 reboiler.

b. Diameter of column

The value of vapor density and liquid density was calculated using $\rho_v = \Sigma \frac{y_i P\, MW}{RT}$ and $\rho_L = \frac{Total\ mass\ flow\ rate\ at\ bottom}{Total\ volumetric\ flowrate\ at\ bottom}$ respectively. To find K_v , we first calculate $\frac{L}{D}(\frac{\rho_v}{\rho_L})^{0.5}$ and the value obtained is 0.0138 then a line is plotted from this value to the 24" curve and drawn horizontally to the y-axis . From graph, K_v=0.395 ft/s. The average surface tension was calculated using $\sigma = A(1 - \frac{T}{T_c})^n$ and $\sigma_{avg} = \Sigma x_{wi}\sigma_i$. Hence, σ_{avg}=47.8669 dyn/cm. By substituting value into $V_{max} = K_v(\frac{\sigma_{avg}}{20})^{0.2}\sqrt{\frac{\rho_L - \rho_V}{\rho_V}}$, V_{max}=3.5561 m/s. By assuming a factor of 0.91 accounts for the downpour area of 9% of the tray , 95 % for foaming and 80 % for flooding. V_{design}=... m/s. The tower cross-sectional area, A is calculated using A = $(\frac{V}{3600})(\frac{1}{\rho_V})(\frac{1}{V_{design}})$, A = $0.8568m^2$ and is equal to $\frac{\Pi D^2}{4}$ hence , the diameter of the column obtained was 1.0445 m .

c. Height of the column

The calculation of height of the column starts by calculating the viscosity value. The viscosity value was calculated using $log_{10}n_{liq} = A + B/T + CT + DT^2$. The average velocity was determined by taking the summation of x_F multiplied by corresponding viscosity, μ . α_{ave} was calculated by multiplying x_{iF} with corresponding α value. Using Locket formula $E_o = 0.492(\mu_L\alpha)^{-0.245}$ to calculate tray efficiency. By assuming tray spacing=12 inches which is equivalent to 0.6096 meters. We can calculate HETP using HETP = $\frac{T}{E_o}$. To determine tower height, H, HETP was multiplied by the number of trays N. The H obtained is 19.0345 meters .

2.2 PACKED TOWER

➢ Distillation Column 3

a. Diameter of column

First of all, two assumptions were made, which are (i) 80% of flooding velocity and (ii) assuming ideal gas behaviour at the distillate. MEA is determined as the light key component, while EG as the heavy key component according to their volatility. The density of each component and their kinematic viscosity at bottom are found from online sources as well as reference books. From pressure-drop correlation for structured packings in Figure 10.6-6, by using CY Wire Mesh structure packing, the packing factor, Fp is 70 ft^{-1}. Since the packing factor is higher than 60 ft^{-1}, the pressure drop at flooding, ΔP_{flood} can be taken as 2.0 in. H_2O/ft. For flow parameters at 0.0951, capacity parameter is found to be 1.45. v_G is calculated to be 4.2796 ft/s from the capacity parameter formula provided which is:

$$v_G\left[\frac{\rho_G}{(\rho_L-\rho_G)}\right]^2 F_p^{0.5} v^{0.05} = 1.45$$

At 80% flooding, the gas flow rate, $G_G = 0.3622\ lbm/s.ft^2$ and converting the unit to obtain $1.7682\ kg/s.m^2$. The inner diameter is calculated by multiplying the total gas flow rate and dividing the G_G with the area of the circle. The final result of diameter of the Distillation Column 3 is 2.3696 m.

b. Height of the column

The calculation starts by determining the light key component and heavy key component. MEA is determined as the light key component, while EG as the heavy key component according to their volatility. By using Antoine Equation, P_{sat} of each component is calculated by assuming a boiling point temperature. The temperature which yields a sum of the P_{sat} of each component equals the pressure of the feed stream is the boiling point temperature of the feed stream, which $T_{bp,feed}$ equals 454.157 K. By comparing $T_{bp,feed}$ and

T_{feed} , it is determined that the feed is a cold feed, hence q > 1, the value of q can be determined by:

$$q = \frac{(H_v - H_L) + C_{pL}(T_B - T_F)}{H_v - H_L}$$

The value of q obtained is q = 1.5817. By using Underwood's Shortcut Method, $1 - q = \Sigma \frac{\alpha_i X_{iF}}{\alpha_i - \theta}$ is used to calculate θ by trial and error , $\alpha_{LK} < \theta < \alpha_{HK}$. The θ calculated is 1.4796. The calculated R_m value is 1.7344 by using $R_m + 1 = \Sigma \frac{\alpha_i X_{iD}}{\alpha_i - \theta}$, followed by assumption of reflux ratio R = 1.5 R_m. Fenske Equation is used to calculate the N_m:

$$N_m = \frac{log((\frac{x_{LD}D}{x_{HD}D})(\frac{x_{HW}W}{x_{LW}W}))}{log(\alpha_L, av)}$$

Erbar-Maddox Correlation is applied in order to determine the $N : N_m$ ratio, which equals to 0.60. N is determined to be 28.8761 theoretical stages, which is 27.8761 trays + 1 reboiler. From Table 10.6-1, by using CY Wire Mesh structured packing, a = 700 m^2/m^3. HELP and height of DC3, H can be calculated by:

HETP = 100/a + 0.1

H = N * HETP

From the calculation, the height of DC3, H is 6.7699 m.

2.3 HEATER 3

In mass balance, using 257.9713 kmol/hr of AM flows from PS to Heater 3 as our basis. The mass flow rate obtained was 4393.5094 kg/hr. Since open system, $\Delta\hat{H} = \dot{Q}$. For inlet stream, $\Delta\hat{H}_1$=-536.9633 kJ/kmol. For outlet stream, $\Delta\hat{H}_{2a}$ = -2064.4338 kJ/kmol, $\Delta\hat{H}_{2b}$= -23351 kJ/mol, $\Delta\hat{H}_{2c}$ = -6614.9941 kJ/kmol, $\Delta\hat{H}_2$ = -18800.4397 kJ/kmol. Thus, the heat exchanger is expected to heat up 257.9713 kmol/hr of AM from 298.15 K to 283.15 K, with a total heat transfer rate of -4711452.749 kJ/hr or -1308.7369 kW.

3.0 OUTCOMES

The table below summarized the key parameters of the designed distillation columns.

Table 3.1: Summary of the Outcomes

Distillation Column	Type	Diameter (m)	Height (m)	Number of trays
1	Tray	1.0445	19.0345	6.0739 trays + 1 reboiler
3	Packed	2.3696	6.7699	-

4.0 CONCLUSION

In conclusion, the tasks assigned which is to design two distillation columns for the amination of 100,000 MTA of Ethylene Oxide (EO) for Monoethanolamine (MEA) production is successfully completed. By using calculation methods such as Underwood's Shortcut Method, Fenske Equation, Antoine Equation, and Erbar-Maddox Correlation, the type of distillation column for DC1 is tray column while that of DC3 is packed column, with diameters of 1.0445 m and 2.3536 m, heights of 19.1138 m and 6.7663 m, respectively. DC1 has 6.0739 trays + 1 reboiler.

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APPENDIX

A.1 MEETING MINUTES

A.1.1 MEETING MINUTES 1

Date : 7/1/2026
Time :2:00-4:00 pm
Location : N02 1-12, FKT
Agenda: Distribution of work

BIL	Matter
1.0	- Our meeting started with discussing the project instruction given by Dr Shuhada in E-Learning. - Every team member actively gives their idea on how we should conduct the project.
2.0	**Distribution of Tasks** - The team leader Yong Zheng Zhao distributed the task as follow : - Distillation Column 1 assigned to Chang Qing Yiu and E Shao Yuan. - Distillation Column 2 and 3 are assigned to Yong Zheng Zhao and Cheong Wei Xin.
3.0	**Selection of Excel File and Closing** - After that we choose to use Yong Zheng Zhao excel file for our project for convenience. - Mr. Yong Zheng Zhao ended our first meeting and the next meeting was scheduled on 10/1/2026.

A.1.2 MEETING MINUTES 2

Date : 10/1/2026
Time :2:00-4:00 pm
Location : Google meet
Agenda: Progress update

BIL	Matter
1.0	**Problem Solving** - Our meeting started with discussion on the problem faced with the calculation. - One of the problems faced is finding density data. One of our teammates suggested that we stick to one source which is Yaws Handbook to ensure data consistency throughout calculation .
2.0	- One of the teammates highlighted the necessity of implementing data linkage within the Excel file and creating a 'Database section' in Excel to put all the data obtained from Yaws Handbook.
3.0	**Closing** - Next, we cross check our calculation on Excel to verify that our calculation aligns with the theoretical principles of Separation Process . - The next meeting was scheduled to be on 14/1/2026.

A.1.3 MEETING MINUTES 3

Date : 14/1/2026
Time :2:00-4:00 pm
Location : Google meet
Agenda: Progress update and report writing

No.	Matter
1.0	- Our meeting started with an update on the progress from each team member regarding their respective assigned tasks. - After summarizing all design parameters in the table using Microsoft Excel. Our team started to discuss how to make the report.
2.0	**Report Writing** - Our team agrees that each member will describe the detailed workflow and methodology of their respective assigned tasks.

A.2 ATTACHED FIGURES

Figure A.2.1: Group Discussion in N02 1-12, FKT

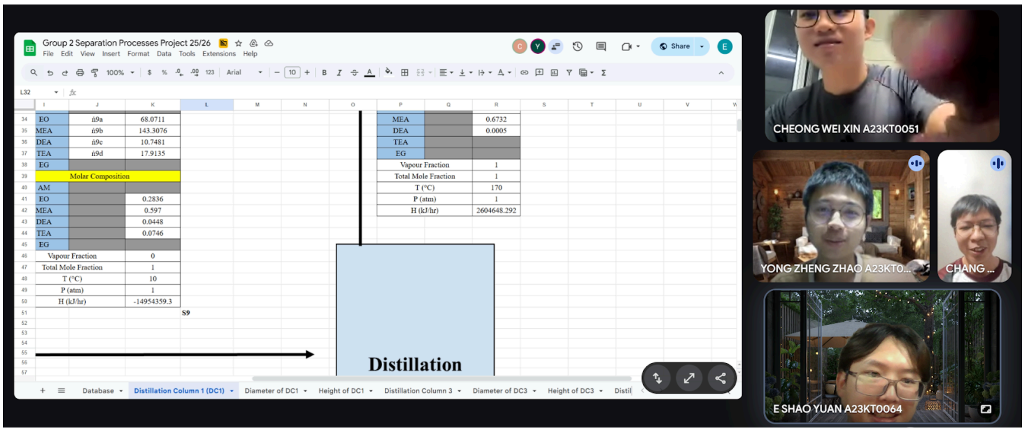

Figure A.2.2: Group Discussion through Google Meet